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NIGHT VISION IMAGING SYSTEM (NVIS) COMPATIBILITY AND VISIBILITY OF THE F-16 COMMON CONFIGURATION IMPLEMENTATION PROGRAM (CCIP) COMMON COLOR MULTI-FUNCTION DISPLAY (CCMFD)

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FOR THE COMMANDER

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13. ABSTRACT *(Maximum 200 words)*

After preliminary operational testing of the Honeywell F-16 Common Configuration Implementation Program (CCIP) Common Color Multi-Function Display (CCMFD), a display intended to incorporate color into night vision imaging system (NVIS) compatible cockpits, some observers felt that the CCMFD did not present video with the same level of detail in NVIS mode as seen in daytime mode. It was also believed that the CCMFD might be interfering with vision through night vision goggles (NVGs), noticeably reducing visual acuity. In addition, pilots wearing NVGs felt that the display was too dim to easily read under certain conditions after prolonged NVG exposure. To address these concerns, the Air Force Research Laboratory, Human Effectiveness Directorate, AFRL/HECV, ran a series of tests with the assistance of the F-16 SPO, the Air Force Reserve and Air National Guard Test Center (AATC/DO), Honeywell, and Lockheed-Martin, to assess the NVIS compatibility and legibility of the CCMFD in its NVIS mode. This paper documents both the results of this testing and an analysis of subjective comments made by observers during a demonstration of the display under the suspect conditions noted by AATC/DO.

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SUMMARY

In an effort to incorporate color into night vision imaging system (NVIS) compatible cockpits, the F-16 System Program Office (SPO) contracted with Lockheed Martin for the F-16 Common Configuration Implementation Program (CCIP). Lockheed contracted with Honeywell's Aerospace Electronic Systems division for the design and development of a Color Multifunction Display (CMFD). After preliminary operational testing, some observers felt that the CCIP Common Color Multi-Function Display (CCMFD) did not present video with the same level of detail in NVIS mode as seen in daytime mode. The CCMFD might also be interfering with vision through night vision goggles (NVGs), noticeably reducing visual acuity, suggesting that the display might not be truly NVIS compatible. In addition, pilots wearing NVGs, which can provide up to 5 footLamberts (fL) of light to the observer's eyes, felt that the display was too dim to easily read under certain conditions after prolonged exposure to bright NVGs.

To address these concerns, the Air Force Research Laboratory, Human Effectiveness Directorate, AFRL/HECV, ran a series of tests with the assistance of the F-16 SPO, the Air Force Reserve and Air National Guard Test Center (AATC/DO), Honeywell, and Lockheed-Martin, to assess the NVIS compatibility and legibility of the CCMFD in its NVIS mode. These tests showed that CCMFD met all existing NVIS B compatibility criteria. The color coordinates chosen by Honeywell allowed for good color discrimination and for an appealing, full-color display. Certain colors were displayed at lower luminance than desired by many observers, but the display met the luminance requirements stated in MIL-L-85762A.

Even though the display met the requirements of MIL-L-85762A, interactions with F-16 pilots with NVG experience during the tests yielded a number of interesting observations. According to one observer, the CCMFD displaying the target pod FLIR video in NVIS mode was too dark to distinguish the level of detail needed for targeting. When information is displayed at high densities, such as the FLIR image, more light is required to discern details. During the demonstration, the Honeywell representative set the display in day mode and adjusted the illumination until the observer said it was bright enough for targeting. At the observer's preferred setting, the luminance of the display measured 90 fL. This much light in the cockpit may degrade the pilot's visual capability looking out of the cockpit and may negatively impact NVG performance. It was discovered that pilots flying Block 30 aircraft in the NVIS mode are forced to set their lighting to a very bright level, nearly to the maximum luminance of which the NVIS lighting is capable, to see features of the horizontal situation indicator (HSI) and fuel totalizer. Again, the additional light may degrade the pilot's visual performance and may negatively impact vision through NVGs.

There appears to be a system-wide compatibility issue with the NVGs. However, initial flight programs have found the displays to be acceptable. The CCMFD's have passed qualification testing and bench testing for NVIS compatibility. Increasing the luminance of the CCMFD will require a design change. The desired luminance level remains unclear at this time. What is needed is an examination of the cockpit as a system to determine what could benefit from change. Areas other than display luminance that may require attention include reexamining the visibility requirements for NVIS displays, tightening the requirements for NVIS compatibility specifically for liquid crystal displays (LCDs), minimizing the windscreen reflectivity, or even improving cockpit display luminance balance.

INTRODUCTION

The F-16 is a single-engine, single or two-seat, multi-role tactical fighter with full air-to-air and air-to-ground combat capabilities. The F-16 System Program Office (SPO), ASC/YP located at Wright-Patterson AFB, OH, is responsible for the development of F-16 systems' capable of meeting the warfighter's operational requirements. F-16 avionics support all-weather air-to-ground attack and air-to-air missions. In support of these missions, the F-16 uses two Common Color Multi-Function Displays (CCMFDs) compatible with a Night Vision Imaging System (NVIS) or Night Vision Goggles (NVGs).

In an effort to incorporate color into night vision imaging system (NVIS) compatible cockpits, the F-16 System Program Office (SPO) contracted with Lockheed Martin for the F-16 Common Configuration Implementation Program (CCIP). Lockheed contracted with Honeywell's Aerospace Electronic Systems division for the design and development of a Color Multifunction Display (CMFD). Honeywell Electronic Systems, Albuquerque NM, developed the CMFD's in the late 1990's. The F-16 CCMFD is intended to be a replacement for the F-16 CFMD, which suffers from serious diminishing material source (DMS) issues. As a result, the F-16 CCMFD was developed using common, industrial grade components. The CCMFD is a 4-inch by 4-inch display and provides the pilot with high-resolution, full color video in different ambient conditions (e.g., full sunlight to low starlight levels). This display was intended to replace the standard cathode ray tube based MFD with which the Block 40 and newer F-16's are currently equipped. The CCMFD's specification required Honeywell to meet MIL-L-85762A, Military Specification, Lighting, Aircraft, Interior, Night Vision Imaging System Compatible requirements.

To determine if the new color multifunction display could be integrated into older aircraft flown by the Air National Guard and Air Force Reserves, the Air National Guard and Air Force Reserve Test Center (AATC/DO) in Tucson, AZ, asked for Honeywell to demonstrate their display on an NVIS compatible aircraft at AATC/DO. A number of researchers from AFRL/HEA, Mesa, AZ, assisted this effort by performing a series of tests intended to assess the NVIS compatibility of prototype cockpit displays and lighting.

After preliminary testing in Tucson, some observers felt that the CCMFD suffered from a few noteworthy problems. First, it did not present video with the same level of detail in NVIS mode as seen in daytime mode. The image quality of the display when set in NVIS mode was not as good as one would prefer for many of the F-16's missions. It was also noted that the CCMFD might also be interfering with or degrading visual performance through night vision goggles (NVGs). A measurable reduction in visual acuity through NVGs was attributed to the CCMFD, suggesting that the display might not be truly NVIS compatible. In addition, pilots felt that the display was too dim to easily read small symbols and characters on the CCMFD under certain conditions after prolonged exposure to bright NVGs. Initially, this was attributed to possible loss of dark adaptation due to prolonged exposure to NVGs, some of which are capable of presenting a 5 fL image to the observer, under the proper conditions.

As a result of these tests, the F-16 SPO asked the Air Force Research Laboratory, Human Effectiveness Directorate, AFRL/HECV, Wright-Patterson AFB to examine the issues noted by AATC/DO and demonstrate the visual phenomena in the laboratory. Before the displays could be made available for laboratory testing, initial studies were restricted to examining the visibility of small characters whose luminance was in the range displayed by the CCMFD. An experiment

was assembled to test the hypothesis that observers adapting to a bright NVG image could have more difficulty reading small, dim display characters. The visual acuity of several observers was measured after prolonged exposure to bright NVGs. After dark-adapting for 10 minutes, the observer's baseline acuity was measured using a self-luminous array of Landolt C's (Figure 1). Then the observer was exposed to a 4 fL NVG output. Visual acuity was measured every 15 minutes for one hour. The experiment was repeated twice, once with the display luminance set to 1.0 fL and again with a display luminance of 0.1 fL. Studies showed acuity to be the same at the end of the hour of exposure as the baseline measurement, indicating that acuity was independent of NVG exposure time.

This result is supported by research conducted independently at AFRL/HEA, Mesa, AZ and documented in a paper soon to be released in the Journal of Aviation, Space, and Environmental Medicine (ASEM) [Howard, Reigler, and Martin, in press]. This paper described an experiment that measured the response time of a number of subjects reading a simulated NVIS compatible altitude direction indicator (ADI) as a function of the log luminance ratio of a bright NVG and a dim display. Howard, Reigler, and Martin noted measurable increases in response time at log luminance ratios of two or greater (Figure 2). The log of the luminance ratios experienced by observers in the AFRL/HECV experiment viewing Landolt C's never exceeded 1.6, minimizing the impact of this phenomenon.

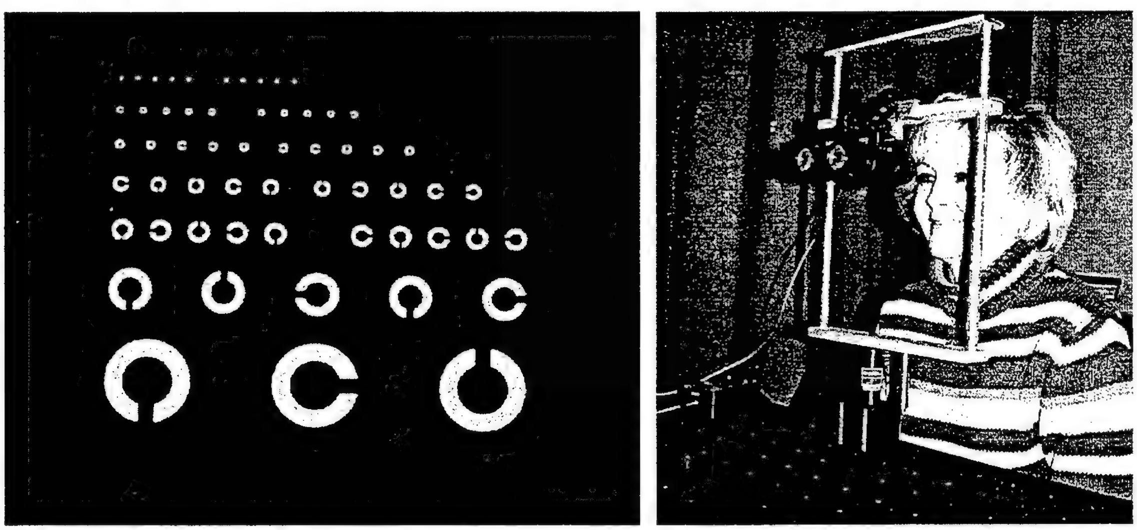

Figure 1. Landolt C's (left) and goggle mount (right) used in preliminary study to assess the visibility of small, dimly lit characters.

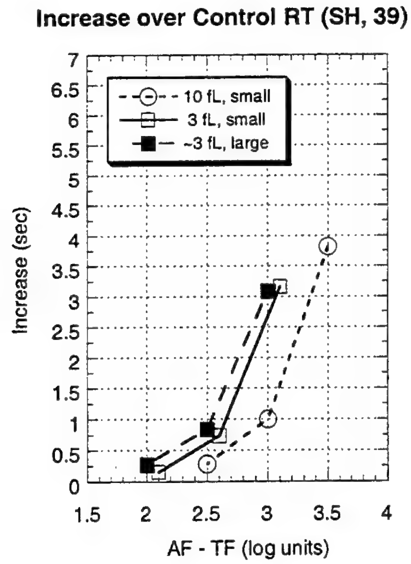

Figure 2. Increase in reaction time as function of luminance ratio in log units for three different targets (10 fL small, 3 fL small, and ~3 fL large) for one observer. [Howard, Reigler, and Martin, in press]

In light of this result, the F-16 SPO, AATC/DO, and Honeywell agreed that the visual interactions between the CCMFD and state-of-the-art night vision systems should be studied in greater detail. At the end of January 2001, Honeywell provided two CCMFD's for examination by AFRL/HECV at Wright-Patterson AFB, OH. This report documents the procedures applied in the analysis of the displays, the data acquired, and the results of demonstrations of the visual phenomena noted at AATC/DO.

MEASUREMENTS AND DATA

To examine the displays, a number of quantitative laboratory tests and demonstrations were held 29 Jan – 2 Feb 2001 at AFRL/HECV. Measurements made to characterize the displays included spectral, NVIS radiance, luminance, luminance uniformity, and character size. In addition, a low-fidelity cockpit simulation was assembled to recreate a number of visual phenomena under controlled conditions that were reported from initial operational testing. The test plan as compiled in January 2001 appears in Appendix A as additional information.

Spectral Measurements

A considerable amount of data could be obtained simply by making spectral measurements of the light emitted from the display. Display radiance, NVIS radiance, luminance, and color coordinates can all be calculated once the spectral content of the emitted light is known. Measurements were made using an Instrument Systems IS 320 radiometer (Figure 3) capable of measuring NVIS radiance. To start the measurements, the display was placed on a stage 24 inches from the radiometer's measurement head. A four-segmented image made up of quadrants of color: red, green, blue, and either black or white, was placed on the display (Figure 4). The radiometer's head was then aligned to each of the four colors and measured in sequence.

Measurements were made at three luminance levels: full NVIS bright, half full bright, and one increment above off. Once all three measurements were completed, the radiometer head was realigned on a different color quadrant of the display and the measurements repeated. To get the fifth color, either black or white, a second quadrant target was displayed and measured. To verify that the red, green, and blue color patches were the same on the two quadrant targets, one color was chosen, measured again from the second quadrant target, and compared to the previous measurements of that color. Data was saved to a computer file for extraction and analysis later. The data extracted on display NVIS A and B radiance, luminance and chromaticity are displayed in Table 1 through Table 6 of this document. Examples of the spectral data obtained in this effort are displayed in Figure 5 through Figure 9 below.

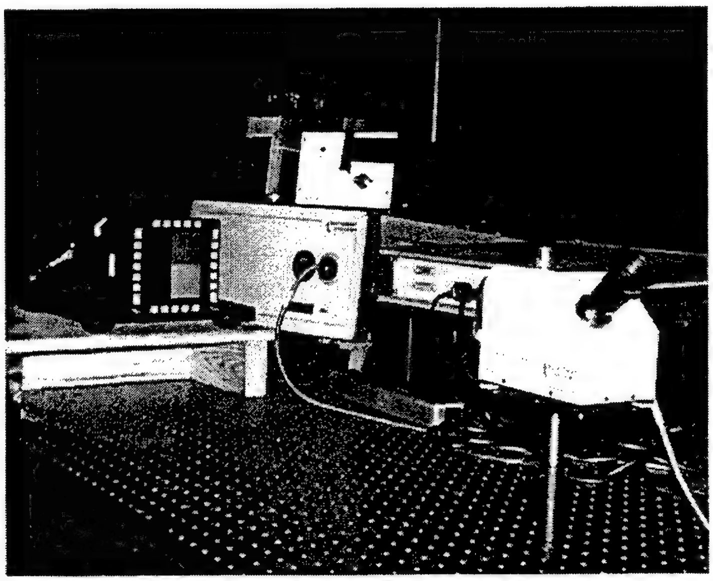

Figure 3. CCMFD in position for spectral measurements.

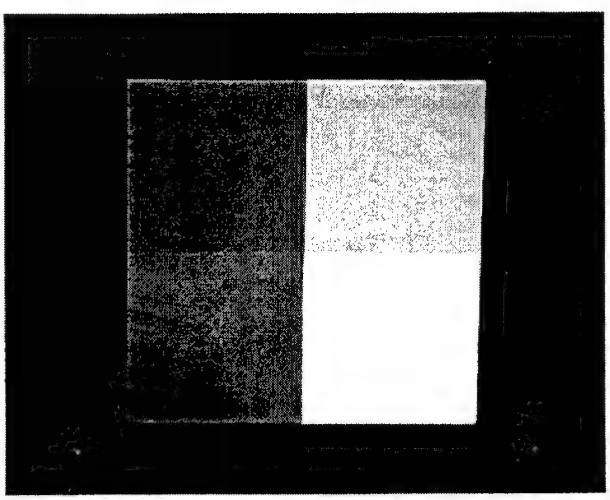

Figure 4. Target used for spectral measurements

Table 1. Display NVIS radiance, luminance, and UCS chromaticity for S/N 902002, display set to full bright.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.35E-08	3.48E-09	0.226	0.4028	0.5306
green	4.47E-09	2.70E-10	0.559	0.1547	0.5497
blue	1.83E-09	2.83E-10	0.118	0.1060	0.4111
white	1.66E-08	1.20E-09	0.878	0.1996	0.5258
black	2.35E-08	1.33E-08	0.003	0.1846	0.5160

Table 2. Display NVIS radiance, luminance, and UCS chromaticity for S/N 902002, display set to half bright.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.18E-08	3.13E-09	0.026	0.4000	0.5311
green	4.37E-09	2.49E-10	0.065	0.1363	0.5601
blue	1.08E-09	5.96E-11	0.014	0.1086	0.4086
white	1.72E-08	1.04E-09	0.103	0.2049	0.5245
black	1.53E-08	4.44E-09	0.003	0.1923	0.5119

Table 3. Display NVIS radiance, luminance, and UCS chromaticity for S/N 902002, display set to one increment above off.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.01E-08	2.29E-09	0.006	0.4123	0.5341
green	2.50E-09	9.67E-11	0.015	0.1388	0.5603
blue	5.30E-10	5.06E-11	0.003	0.1028	0.3982
white	1.75E-08	8.83E-10	0.022	0.2037	0.5230

Table 4. Display NVIS radiance, luminance, and UCS chromaticity for S/N 901002, display set to full bright.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.64E-08	5.03E-09	0.245	0.4067	0.5306
green	3.66E-09	3.02E-10	0.540	0.1409	0.5563
blue	2.43E-09	4.97E-10	0.108	0.1108	0.3887
white	1.80E-08	1.70E-09	0.833	0.2012	0.5213
black	1.75E-08	6.85E-09	0.003	0.1775	0.5036

Table 5. Display NVIS radiance, luminance, and UCS chromaticity for S/N 901002, display set to half bright.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.58E-08	4.13E-09	0.029	0.4047	0.5299
green	3.39E-09	1.41E-10	0.066	0.1401	0.5565
blue	1.56E-09	9.12E-11	0.013	0.1088	0.3879
white	1.74E-08	1.44E-09	0.104	0.2007	0.5202
black	6.86E-08	5.51E-08	0.000	0.2260	0.5413

Table 6. Display NVIS radiance, luminance, and UCS chromaticity for S/N 901002, display set to one increment above off.

	NVIS A	NVIS B	Luminance	u'	v'
red	5.20E-08	3.55E-09	0.006	0.4110	0.5324
green	2.85E-09	1.34E-10	0.014	0.1392	0.5597
blue	7.69E-10	3.85E-11	0.003	0.1073	0.3755
white	1.95E-08	1.47E-09	0.020	0.2059	0.5171

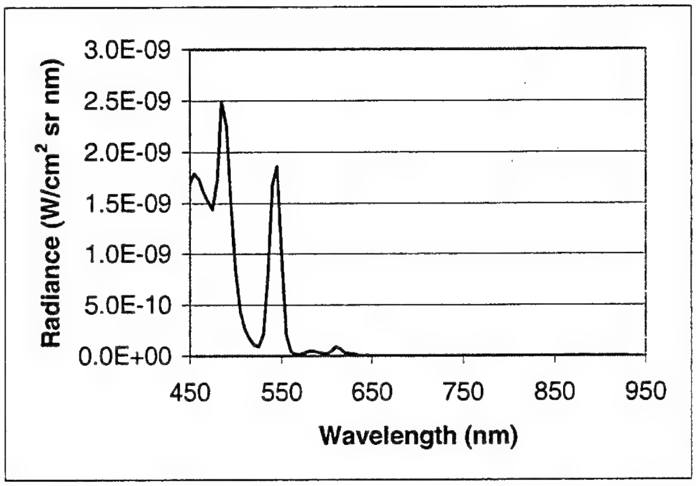

Figure 5. Radiance as a function of wavelength for CCMFD blue, display set for full brightness.

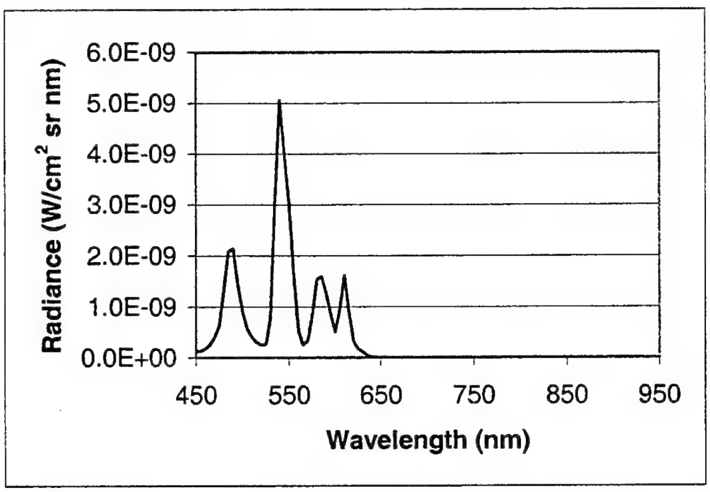

Figure 6. Radiance as a function of wavelength for CCMFD green, display set for full brightness.

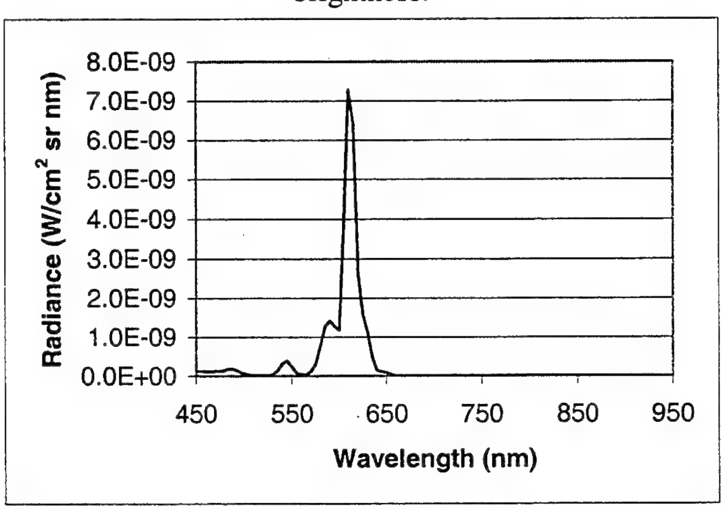

Figure 7. Radiance as a function of wavelength for CCMFD red, display set for full brightness.

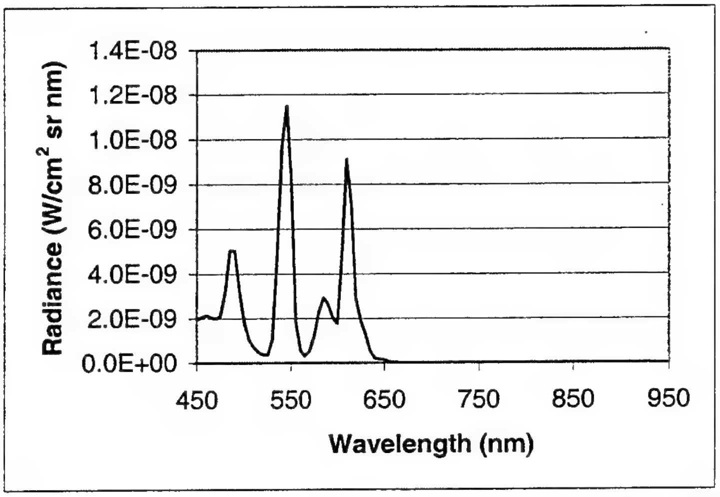

Figure 8. Radiance as a function of wavelength for CCMFD white, display set for full brightness.

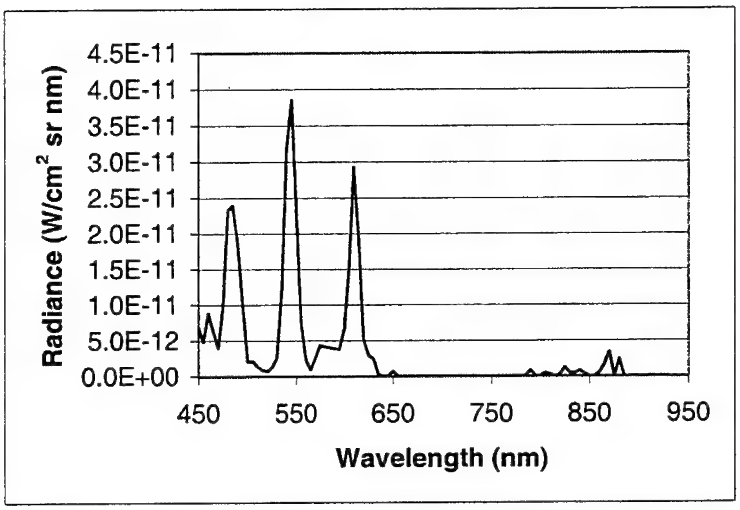

Figure 9. Radiance as a function of wavelength for CCMFD black, display set for full brightness.

Luminance Uniformity

In addition to the spectral measurements described in the previous section, the F-16 SPO asked for an evaluation of the luminance uniformity of the CCMFD to verify that the display met their uniformity requirement. To save time, only one display was measured. The test required the display to be illuminated all in one color. The display's luminance was measured for nine locations (Figure 10) using a Minolta hand-held photometer placed 43 inches from the face of the display. The photometer's one-degree field of view measured a 0.75-inch diameter circle at the display, insuring that there was no overlap between measurements. Display luminance uniformity was measured for red, green, blue, and white. The data collected are presented in this report in Table 7.

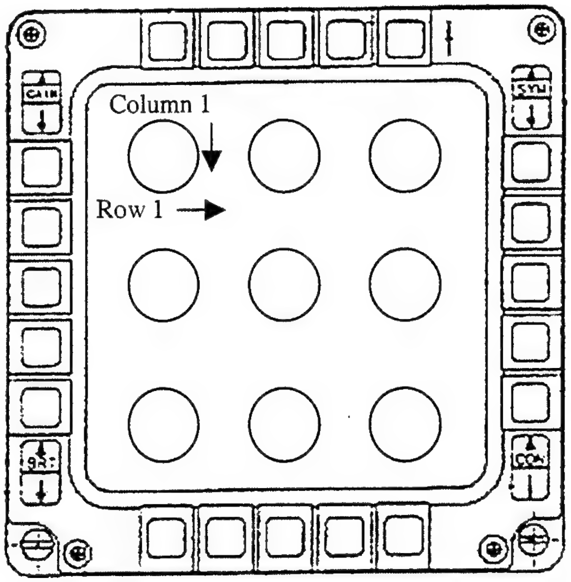

Figure 10. Relative locations on the CCMFD of the luminance uniformity measurements

Table 7. Luminance uniformity of CCMFD 902002.

White	**Col 1**	**Col 2**	**Col 3**		**Red**	**Col 1**	**Col 2**	**Col 3**
Row 1	1.082	1.034	1.091		**Row 1**	0.251	0.241	0.251
Row 2	1.024	1.005	1.023		**Row 2**	0.241	0.241	0.241
Row 3	0.956	0.947	0.956		**Row 3**	0.232	0.232	0.232
Green	**Col 1**	**Col 2**	**Col 3**		**Blue**	**Col 1**	**Col 2**	**Col 3**
Row 1	0.666	0.647	0.676		**Row 1**	0.145	0.135	0.145
Row 2	0.647	0.628	0.637		**Row 2**	0.135	0.135	0.135
Row 3	0.589	0.589	0.599		**Row 3**	0.126	0.126	0.126

The most noticeable trend found in luminance uniformity was a decrease in display luminance as the measurements moved farther from the top edge of the display. In addition, the upper corners tended to be brighter than the lower corners. The percent uniformity (*Uniformity*) was calculated for each tested color using the following equation:

$$Uniformity = \frac{Max - Min}{Max} \times 100\%$$

Here, *Max* and *Min* are the maximum and minimum luminance respectively, measured for a particular color from the display. The resulting calculated percentages are listed in Table 8.

Table 8. Luminance uniformity of the CCMFD (S/N 902002) for the four measured colors expressed as a percentage.

Color	**% Uniformity**
Red	7.7
Green	12.9
Blue	13.3
White	13.3

Character Size Measurement

One of the most pressing issues left unexamined by initial tests at AATC/DO in Tucson was the size of the characters that were considered difficult to read. The impact of the physical size of a target on its visibility is easy to understand. Larger targets are simply easier to see [Cobb and Moss 1928]. Due to the nature of the tests conducted at AATC/DO, researchers were unable to measure the size of the characters displayed on the CCMFD. The symbol sets used were not the symbology commonly used on the F-16 MFD, but rather were the result of the manufacturer's best guess at what the aircraft symbol generator might present on the display. To display this symbology, characters were generated on a personal computer and relayed to the displays through considerable electronics.

To measure the characters of interest, the individual files were first printed in the proper aspect ratio using a high quality laser printer (600 dpi). Symbols were then measured from the paper using a 20X loupe and reticule. To check these measurements, a number of characters were measured both off the paper printouts and directly from the displays themselves using the same loupe and compared. Comparison of the two sets of measurements showed both approaches to yield the same results to within the accuracy of the measurement loupe.

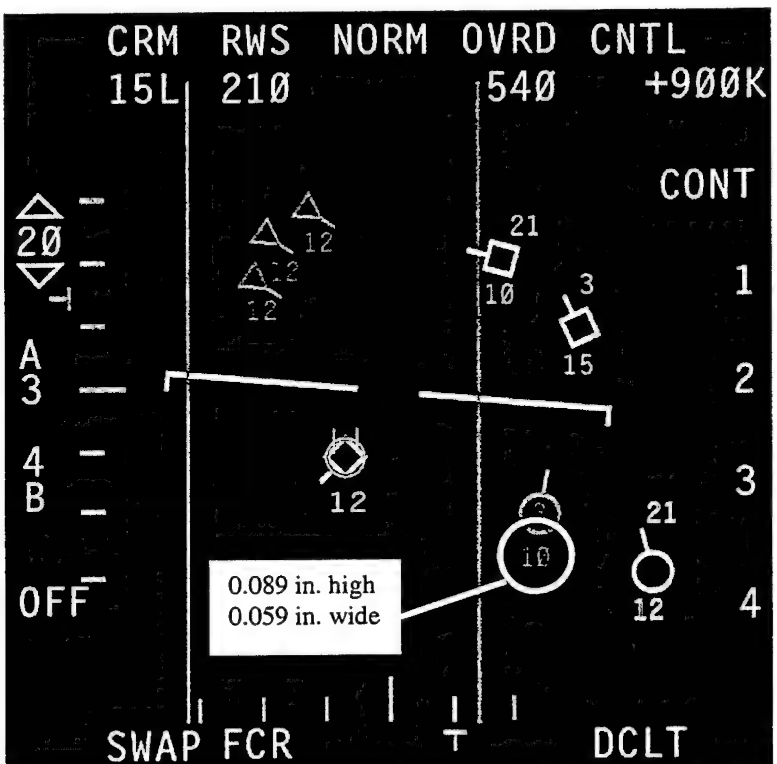

Figure 11. Conceptual image of tactical data displayed on the CCMFD. Figure reproduced to actual scale (4 inches X 4 inches).

The smallest, dimmest characters (the characters most difficult to see) were the blue letters and numbers, measuring 0.089 inches high and 0.059 inches wide. Observing these symbols at 28 inches, the nominal observation distance for this display in the F-16, the characters would be 10.9 arc minutes tall. This translated to a Snellen acuity of about 20/43.5. One should note that the displayed characters were not similar to those commonly used in acuity testing, and did not

exhibit the defined length to width to stroke aspect ratio. Therefore, this analysis only yielded an estimate of Snellen acuity. The actual visual acuity of these characters was undoubtedly worse.

At the writing of this report, it was unclear if the symbols presented in the laboratory at AFRL/HECV were the same as those considered difficult to read at AATC/DO. Many believe that the characters used at AFRL/HECV had thicker line widths, making them easier to read. The usefulness of these measurements in explaining the objectionable conditions is, therefore, somewhat questionable for two reasons. First, the symbols might not be the ones found objectionable at AATC/DO in November. Secondly, they do not accurately represent the symbols that would be displayed in an operational aircraft. However, these measurements did establish the size of characters used in AFRL/HECV demonstration.

Gain and Spectral Sensitivity

The two night vision goggles loaned to AFRL/HECV by AATC/DO were both AN/AVS-9 (F4949) devices manufactured by ITT Night Vision Industries. One was an older C model AN/AVS-9, S/N 0568, having lower gain and a slightly different focus mechanism than state-of-the-art night vision devices currently flying in the US Air Force. The other was a new G model AN/AVS-9, S/N 5587, exhibiting high gain and high optical performance. Both were tested for gain and spectral sensitivity established procedures [Task, Hartman, Marasco, and Zobel 1993]. Brief descriptions of the procedures and the data acquired from the two goggles used in the demonstration are provided in Appendix B and C as additional information.

Vision Demonstration

To better examine the interaction between the display, the cockpit, and the night vision goggle, a demonstration was assembled in a laboratory at AFRL/HECV. This demonstration placed observers in a simulated cockpit with the CCMFDs and required them to assess their own visual performance under a number of conditions. Observer comments were noted and reviewed to determine the combinations of conditions under which visual performance was unacceptably degraded.

Conditions and Procedure

To assemble the cockpit simulation, the displays were placed in the correct geometry with respect to the observer's eye position using information provided by Lockheed-Martin (Figure 12, Table 9). The distances listed in Table 9 are in inches and are relative to the observer's correct eye position. In Table 9, the column labeled **Distance** lists the distance to the displays from the eye position. The column labeled **Horizontal** describes the separation between the displays. The column labeled **Vertical** describes the distance the displays were placed below the observer's line of sight.

Table 9. Coordinates of the four corners and the center of the two CCMFD's as positioned in the simulated cockpit. Distances are in inches and are relative to the observer's correct eye position.

	Distance	**Horizontal**	**Vertical**
Upper Outboard	28.6	±8.8	-12.5
Upper Inboard	28.6	±4.5	-12.5
Center	28	±6.7	-14.5
Lower Outboard	27.5	±8.8	-16.5
Lower Inboard	27.5	±4.5	-16.5

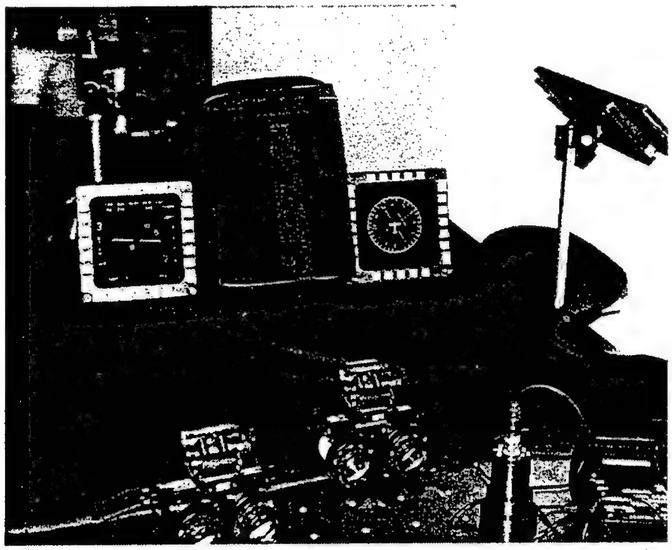

Figure 12. Low-fidelity cockpit simulation used to demonstrate visual interactions.

An electro-luminescent (EL) panel was mounted to a post near the displays to add additional NVIS "compatible" light, simulating the effect of other lights in the cockpit. The light from the EL panel was diffused by reflecting it off a large, flat, white surface. A 3X3 NVG resolution target (Figure 13) was placed in space 15 feet from the observer position. The target was provided as a visual performance reference to assist the observers in assessing the impact of the different display and lighting conditions. A sheet of Plexiglas was placed between the observer and the acuity target to reflect EL light back towards the observer. This created a veiling luminance that could interfere with visual performance (Figure 14) as a windscreen would in a real cockpit.

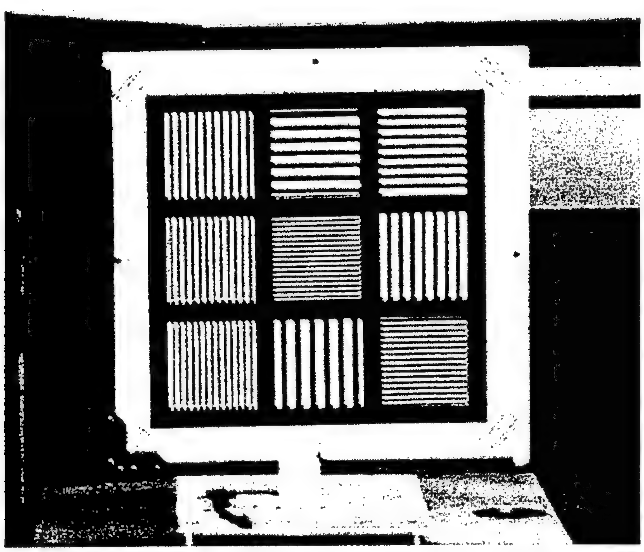

Figure 13. 3X3 NVG resolution target.

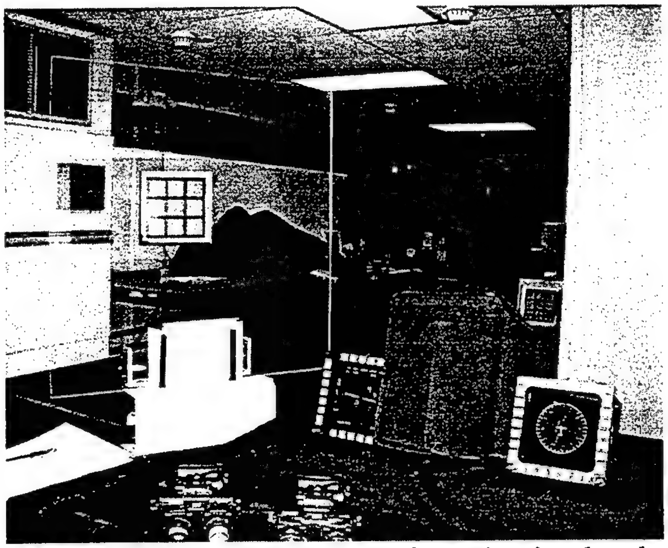

Figure 14. View of a resolution target from the simulated cockpit.

The experimental conditions examined were based on the observations made at AATC/DO. It was expected that exterior target luminance and CCMFD luminance would have the largest impact on visual performance. In addition, the amount of additional cockpit lighting was also expected to affect vision, making it a logical factor to include. Finally, the level of NVG performance was also suspected, not necessarily of being a factor affecting vision by itself, but of being part of an interaction involving the display luminance and cockpit lighting. A factor describing goggle performance was therefore included. One should note that newer NVGs tend to have improvements in a number of parameters, including higher gain, higher spectral sensitivity, and different minus-blue filters, making them perform differently than older goggles. Due to the limited number of NVGs available for this demonstration, it was impossible to differentiate the effects of the different NVG parameters on vision.

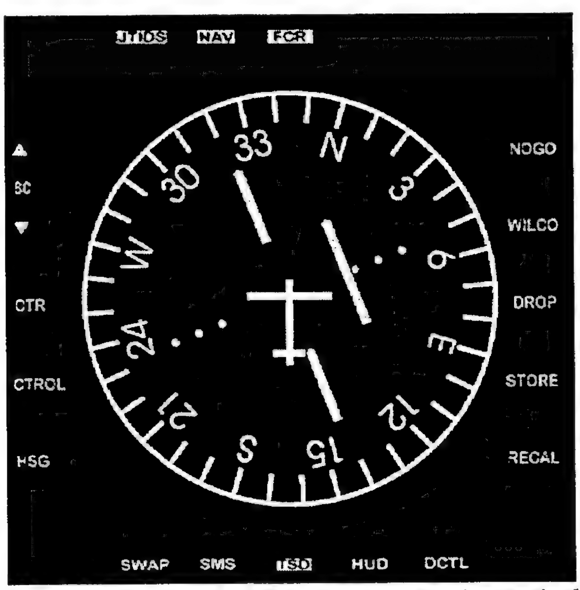

Figure 15. CCMFD compass demonstration. This image is not indicative of information currently displayed on the F-16 MFD.

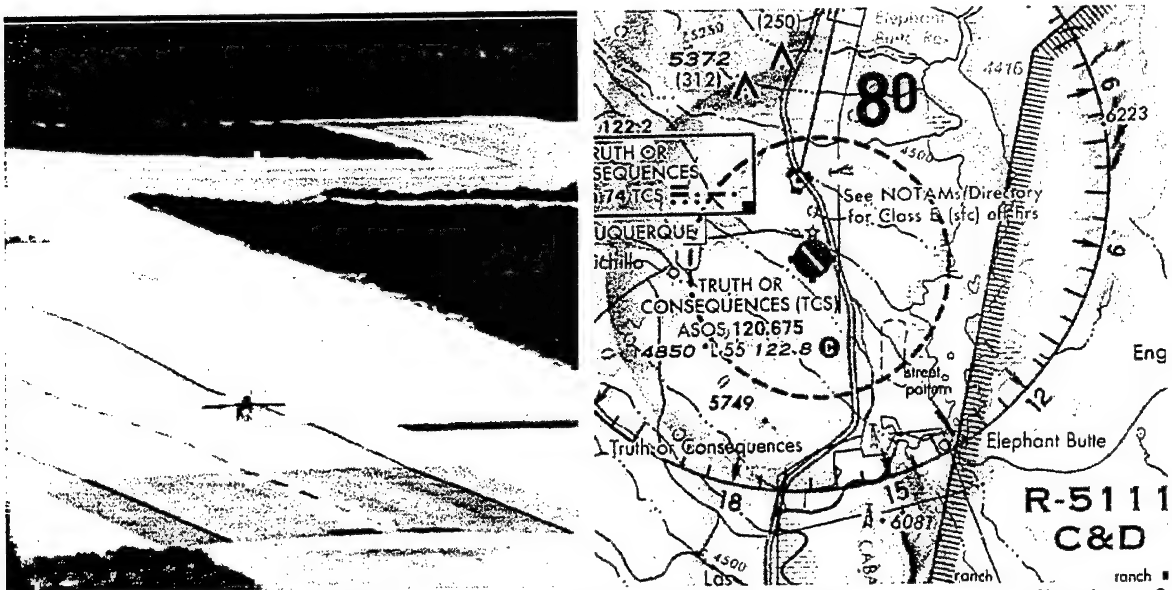

Figure 16. FLIR image (left) and full color map (right). Both images are not indicative of information currently displayed on the F-16 MFD.

Two levels of each factor examined were used in the demonstration. The target luminances presented to the observers were half moon ($1.18X10^{-2}$ fL) and half starlight ($2.94X10^{-4}$ fL) using a blackbody source having approximately a 2850 degree K color temperature. The bright and dim conditions for the CCMFD were established not by the luminance of the individual characters, but by the amount of the display illuminated. For the dim conditions, images having bright characters on a black background, such as the tactical display (Figure 11) and a compass (Figure 15), were displayed. The bright condition employed images where the whole display was illuminated to some degree, such as forward-looking infrared (FLIR) imagery and a full-color moving map (Figure 16). One should note that these images were intended for marketing demonstrations only and do not accurately reflect information normally displayed on the F-16 multi-function display. Two levels of additional extraneous NVIS "compatible" lighting were also examined in the demonstration. The two levels used were 1 fL to represent the luminance level commonly found in bright NVIS compatible cockpits ("on"), and no additional light ("off"). As noted earlier, the two NVGs examined were both AN/AVS-9's. One was a C model with a Class A minus-blue filter, the other a G model with a Class C minus-blue filter. Observers were presented all combinations of these four factors, creating 16 experimental conditions. The output luminances from the two NVGs for the deferent conditions were measured and recorded in Table 10. In addition, Table 10 includes the output luminances measured through the goggles with the displays turned off. These conditions were not presented to the observer, but were measured because they were considered important to the analysis of the displays.

Table 10. Goggle output luminances for the experimental conditions.

			C Mod		G Mod	
Target	**Display**	**Cockpit**	**Left**	**Right**	**Left**	**Right**
Half Moon	Dim		1.812	1.772	4.359	3.946
Half Moon	Dim	+	1.810	1.771	4.354	3.946
Half Star	Dim		0.399	0.312	0.871	1.000
Half Star	Dim	+	0.438	0.372	0.942	1.124
Half Moon	Bright		1.820	1.772	4.452	3.944
Half Moon	Bright	+	1.818	1.773	4.428	3.943
Half Star	Bright		0.429	0.312	0.951	0.980
Half Star	Bright	+	0.465	0.372	1.032	1.063
Half Moon	Off		1.610	1.775	4.408	3.915
Half Moon	Off	+	1.607	1.775	4.393	3.918
Half Star	Off		0.335	0.343	0.885	0.906
Half Star	Off	+	0.390	0.411	0.955	1.006

Before the start of a day of demonstrations, lab personnel focused both goggles and tested the target luminance levels. At the start of a demonstration session, personnel who wished to have their comments recorded provided certain demographic data including, but not limited to, name, age, eyewear, and NVG experience. Other pertinent information, such as the types of aircraft an observer flew, would also be recorded if necessary. Then observers were allowed to dark-adapt for 10 to 15 minutes. During this time, instructions regarding the task were given. Observers were also told that the goggles were pre-focused and that they were not to adjust them. The observer would first look through the C model NVG at the acuity target and call off the number of gratings that they could resolve. Then the observer was asked to continue looking through the goggles at the acuity target for approximately 5 minutes. This 5-minute adaptation was intended to readjust the observer to the bright goggle output and was only performed once at the beginning of the session. The observer was then instructed to look at the display and report what they could or could not see.

The experimenter running the demonstration asked several questions. For the dim CCMFD conditions, observers were asked if they could see all of the colors on the display. They were asked if they could see all of the displayed symbols and the numbers accompanying the symbols. Observers were asked about the appearance of the colors. They were asked if the colors looked like they should, such as, could they readily interpret red as red, blue as blue, white as white, and so forth. Observers were asked if any of the colors washed out when they looked at the display. In addition, observers who were also pilots were asked if they could see the display well enough to accomplish a mission. The observer then looked through the G model NVG at the acuity target and noted the number of gratings they could resolve. They then continued to look through the goggles at the acuity grating for approximately 1 minute and then looked back at the display. The same questions were asked as above. These procedures were repeated for all the conditions alternating between the C and G model NVGs.

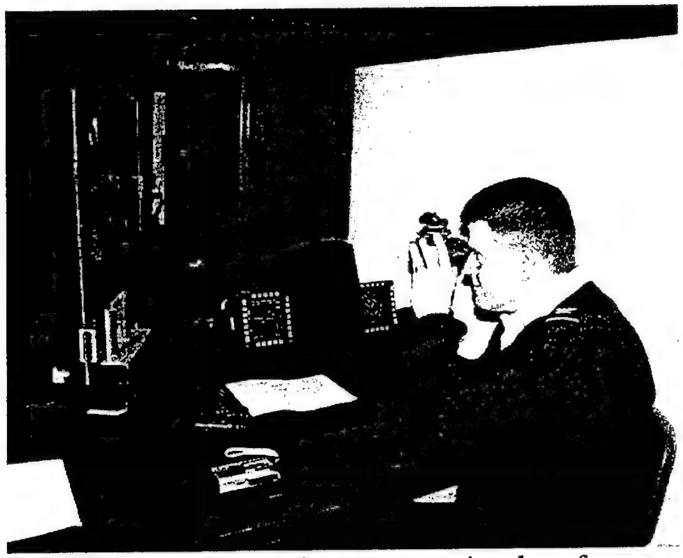

Figure 17. Observer ready to assess visual performance.

Discussion

Observers largely felt that the symbols and imagery presented by the displays were visible. The colors displayed with greater luminance, such as white, green and yellow, were considered easily visible. Red and blue were more difficult to see but were still considered visible to a large percentage of the observers. The majority of the observers also considered FLIR imagery displayed on the CCMFD visible. However, pilots felt they needed more detail to accomplish a ground attack mission. One should note that the FLIR imagery used in the demonstration was originally target pod video that was transformed into an MPG file. This conversion degraded the video somewhat. This would have a negative impact on the visibility of details in the image. However, significant additional detail could be obtained from the FLIR video by simply increasing the display luminance, indicating that the visibility of the video was limited by the observer's eye during the demonstration, not the CCMFD. This was demonstrated in the laboratory when one pilot was allowed to adjust the display luminance and contrast to what he considered optimal using the display's daylight mode. Considerable additional detail became visible including ground crew near parked aircraft and aircraft features such as the refueling probe on an A6 Intruder. The display luminance of this "optimal" setting was measured to be approximately 90 fL using a handheld photometer. Unfortunately, using a display capable of that brightness at night is impractical for many reasons, such as increased cockpit reflections and veiling luminance. The probability of any manufacturer building a 90 fL display that is NVS compatible in the near future with existing technology is low.

One observer stated it most clearly by saying, "I didn't see a problem here… …but I would be hesitant to say the plane does not have a problem." The demonstration employed a subjective, simple task that did not duplicate the conditions under which the display is normally employed. To improve the demonstration and better quantify the display would have required more time and resources than were available at the time of the CCMFD evaluation. As noted earlier, observers were not all pilots. Most observers did not have a clear idea about how NVGs and NVIS lighting interact with the human visual system. Observers were also allowed to assess their own visual performance since time did not allow for a more objective assessment. In addition, observers were allowed to look at the display longer than what a pilot would,

improving their visual performance since target duration often affects target visibility [Cobb and Moss 1928].

There were a number of concerns raised by the pilots who saw the cockpit simulation. The first issue was with the additional NVIS cockpit lighting. Pilots felt that the lighting present in the simulation was not bright enough and there were too few light sources placed around the cockpit. In addition, it was determined through questioning that pilots fly with their cockpits brighter than simulated in the demonstration. A number of small but critical displays, the Horizontal Situation Indicator and fuel totalizer in particular, must be bright enough for the pilot to read in flight. In order to increase the luminance of those displays, pilots are forced to increase the luminance of all of their cockpit instruments since the luminance of a particular instrument cannot be adjusted independently of the others in the cockpit.

Non-pilot observers tended to have their attention drawn to large, easy to see objects in the FLIR video, such as the airplane on the runway (Figure 16). Targets of interest to a pilot attacking a ground target will be relatively small and probably camouflaged. There was no easy alternative by which more realistic targets could be embedded in the marketing demonstration video, making this aspect of the demonstration more realistic. There were a number of small, low contrast details in the video. But only one observer noticed any of these. Therefore, it is difficult to conclude that the relevant details would always be visible when displayed at the luminance levels examined. Observers could not comment on the visibility of targets they simply could not see if they did not know they were there.

CONCLUSIONS AND COMMENTS

The data gathered in this effort showed that the Honeywell CCMFD passed MIL-L-85762A NVIS B specification, as required. The color balance between red, green, and blue allowed the display to achieve the full color sought for applications like moving maps. Also, the color coordinates selected by Honeywell for red, green, and blue were well chosen, allowing for easy color discrimination and identification. In general the Honeywell CCMFD is not NVIS A compatible as it was capable of emitting a significant amount of red light. However, this was not a program requirement.

The visibility of the display was found to be acceptable but marginal. This could be improved by increasing the luminance in the NVIS mode. However, increasing the luminance could negatively impact NVIS compatibility. Characters on displays like the compass and the tactical display (bright characters on a dark background) could be made larger to improve visibility. Unfortunately, it is unlikely that the display itself could be made larger since the F-16 MFD is currently limited in size due to cockpit constraints.

This effort found no evidence of reduced visual performance due to the observer adapting to a bright NVG at the display and goggle luminances examined. However, this evaluation only examined the display when set to full NVIS brightness. Research suggests that should the display be set to a dimmer luminance, bright adaptation to the NVG might become an issue. Since pilots tend to set the luminance of their NVIS compatible displays to nearly maximum, it is unlikely that the Honeywell CCMFD would be set to anything but full brightness.

In the future, a more controlled experiment should be conducted to accurately quantify visual performance under the luminances produced by the Honeywell CCMFD and study the

interaction between the display and NVGs. This research should examine more realistic conditions. Additional and brighter cockpit lighting should be included to more accurately simulate the NVIS cockpit. Observers should be given a primary task that occupies most of their attention and be restricted to quick glances at the display symbology. Finally, a real F-16 canopy should be included in the simulated cockpit to induce the proper reflection intensities and geometries, which may play a larger role than initially suspected.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the organizations and people who, through much coordinated effort, brought this research to fruition. First, the authors would like to thank Lt Col Steve Coubrough and Maj Jim Henderson of AATC/DO for their initial work describing and documenting their concerns about the CCMFD and their personal assistance and the loan of equipment instrumental to the display's analysis. In addition, thanks are extended to Catherine Griffin, Ted Wood, and Brian DeBruine of Honeywell for supplying the displays and necessary technical support to run them. Also, the authors would like to thank Robert Colby and Laura Durnell of Lockheed-Martin, for supplying the necessary information on the F-16 cockpit for the proper assembly of the simulated cockpit. We would like to thank Maj Kurt Kolch of the Air National Guard headquarters (HQ ANG/AQ) for his active interest in this effort. Thanks are extended to the F-16 SPO (ASC/YP) for providing much of the coordination between organizations and many of the pilots and observers used in the assessment. Finally, special thanks are extended to Fred Meyer (AFRL/HECV), Maryann Barbato, David Sivert, Sharon Dixon, Martha Hausman (Sytronics, Inc.), Terry Trissel, and Robert Schwartz, (Logicon Technical Services Inc.), for their invaluable assistance in the setup and execution of the laboratory bench testing and the visual demonstration.

BIBLIOGRAPHY

Cobb, P.W., Moss, F.K. (1928) The four variables of the visual threshold, *Journal of the Franklin Institute*, *205*, Issue 831, 831-847.

Cobb, P.W., Moss, F.K. (1928) Four Fundamental Factors in Vision, *Transactions of the Illuminating Engineering Society*, *22*, no. 5, 496-506.

Howard, C., Reigler, J., and Martin, E. (in press) Light adaptation: night vision goggle effect on cockpit instrument reading time, *Journal of Aviation, Space, and Environmental Medicine.*

Military Specification, *Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible*, MIL-L-85762A.

Moon, P., Spencer, D.E. (1944) Visual data applied to lighting design, *Journal of the Optical Society of America*, *34*, 605-617.

Task, H.L., Hartman, R.T., Marasco, P.L., Zobel, A.R. (1993) *Methods for measuring characteristics of night vision goggles*, (Tech. Rep. No. AL/CF-TR-1993-0177 (DTIC# AD-A277 046)), Air Force Materiel Command, Wright-Patterson AFB, OH.

APPENDIX A

F-16 Common Color Multi-Function Display (CCMFD) & Night Vision Goggles (NVG) Compatibility and Visual Acuity Test Plan 8 Jan 01

Objective: Determine and compare the F-16's CCMFD performance characteristics with the NVIS Military Standard (MIL-L-85762A) and assess the impact of the F-16 CCMFD operational performance on an observer's visual performance when using NVGs.

1. The compatibility test will be conducted by personnel from the Air Force Research Lab, Wright-Patterson AFB OH with support from Honeywell, Albuquerque NM, LM Aerospace, Fort Worth TX, ASC/ENAS, Wright-Patterson AFB OH, and F-16 System Program Office, Wright-Patterson AFB OH. The tests will, at a minimum:

    a. Measure spectral radiance of the CCMFD in day, night, and NVIS mode.
    b. Measure luminance (Display) and illuminance (Environment)
    c. Measure symbology/character size
    d. Demonstration of visual performance with Class B and Class C NVGs in a simulated cockpit environment

2. Required Assets/Data/Personnel:

    a. Two F-16 CCMD's and associated equipment required for CCMFD operation (Honeywell)
    b. Video Generator or PC with applicable TAD pattern (Honeywell/AFRL)
    c. Class B and Class C Night Vision Goggles and associated spectral curves (AFRL/ANG)
    d. Dark Room (AFRL)
    e. Photometer (AFRL)
    f. Spectroradiometer (AFRL)
    g. Visual acuity chart (AFRL)
    h. Apparatus for generating a veiling luminance visible to an NVG (AFRL)
    i. Barium sulfate target (AFRL)
    j. F-16 pilots from the F-16 SPO (F-16 SPO)
    k. Measured Spectral Radiance data of the MFD, CMFD, and CCMFD, along with the associated LCD curves for the OIS and APC LCD Glass (LMTAS/Honeywell)

3. CCMFD TESTING: The CCMFD's will display a video test pattern and a TAD test pattern. The CCMFD's luminance levels will be set at full brightness, mid-level brightness, and low-level brightness. Display spectral measurements content, NVIS radiance, and luminance will be measured at representative settings and conditions. The illuminance from the display will

be measured from a barium sulfate target placed in a position relative to the display that approximates the location of the pilot's chest and recorded. Symbology/character size for the displayed patterns will also be measured.

4. NVG LIGHTING DEMONSTRATION: A demonstration will be assembled and made available to volunteer observers who would like to experience conditions under which interactions between the CCMFD and an NVG may interfere with visual performance. The two CCMFD's will be positioned as they would be in an F-16 cockpit with respect to a chair for an observer. A target will be placed 20 feet from the observer's position. Observers will be allowed to dark adept for ten minutes. Then, observers will be asked to view the target through NVGs under simulated starlight illumination, once for each NVG of interest. Observers will then be presented with a series of visual conditions, simulating different operational situations, and asked to observe the target through NVGs. Visual conditions will be generated by changing NVG type, target illumination, the image displayed by the CCMFD and its luminance, and by introducing a controlled amount of veiling luminance. Observer comments will be recorded.

5. All data will be recorded and analyzed for NVIS Mil-Std and NVGs compatibility. A report will be written to summarize test data and provide conclusions and recommendations.

APPENDIX B

The spectral sensitivity of the two AN/AVS-9 goggles used in the demonstration was measured to confirm the type of minus-blue filters present in the goggles' objective lenses. The procedure used was designed to measure how sensitive an NVG is to different wavelengths of light. However, this is not a measurement of image intensifier tube photocathode responsivity as required by the image intensifier assembly specification, MIL-I-49428. In the procedure described here, measurements were made on the entire system, including the NVG minus-blue filter, objective and eyepiece lens transmissivity, and phosphor response, yielding a more realistic assessment of NVG performance.

A Tungsten-Halogen bulb, approximately a 3100K black body radiator, broadband, high intensity light source was activated and allowed to stabilize. One should note that any light source capable of emitting a measurable amount of light across the spectral range of NVG sensitivity could also be used. The light from the broadband source was injected into a monochromator. Narrow band, near monochromatic light from the monochromator was then dumped into one port of the integrating sphere to make it more uniform. The NVG under test was then focused to infinity and aligned into the integrating sphere so that the sphere output overfilled the NVG field of view. A photometer was then aligned so that it measured the center of the test NVGs field of view. The photometer field of view must be smaller than the field of view of the NVG under test. The field of view of the Hand-Held Night Vision Photometer normally used in this procedure was 20 degrees. NVG output luminance was then measured over the wavelength region of interest, 400 to 930 nm, in 10 nm increments. Measurements can be made at input wavelength increments finer than 10 nm if available equipment allows.

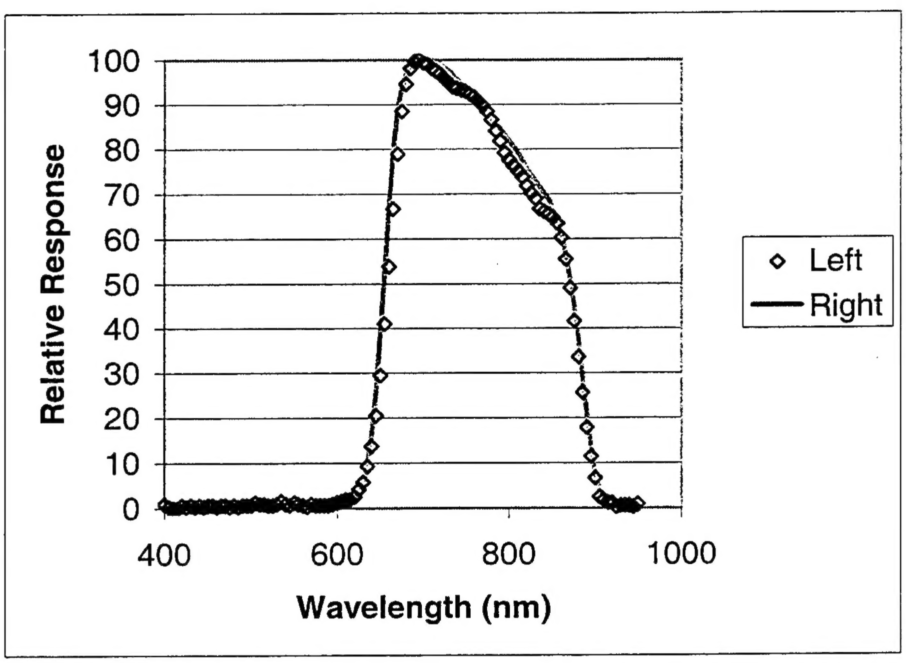

Figure 18. Spectral sensitivity for the left (diamonds) and right (line) oculars of the AN/AVS-9, G model, S/N 5572, used in the visual performance demonstration.

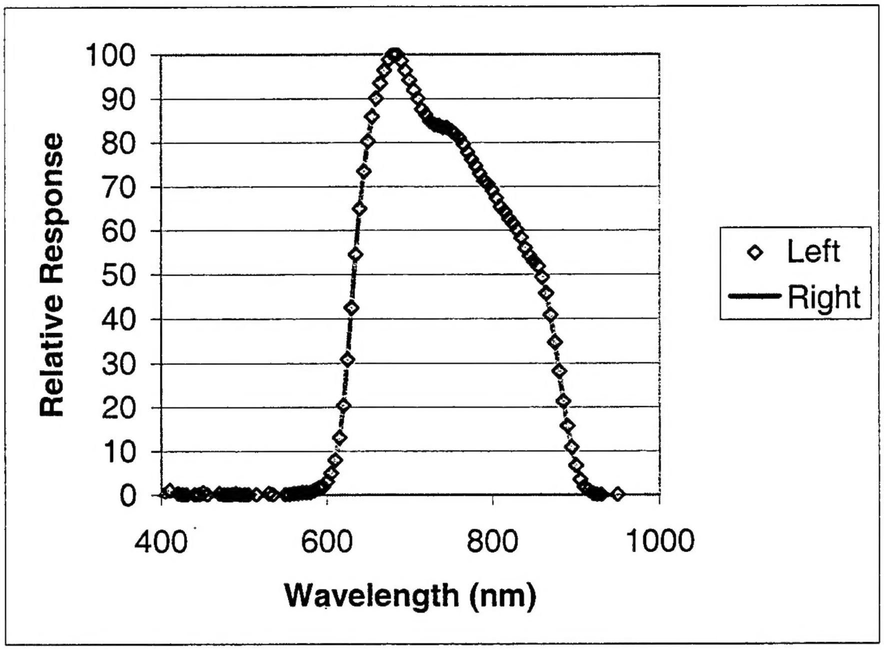

Figure 19. Spectral sensitivity for left (diamonds) and right (line) oculars of the AN/AVS-9, C model, S/N 0358, used in the visual performance demonstration.

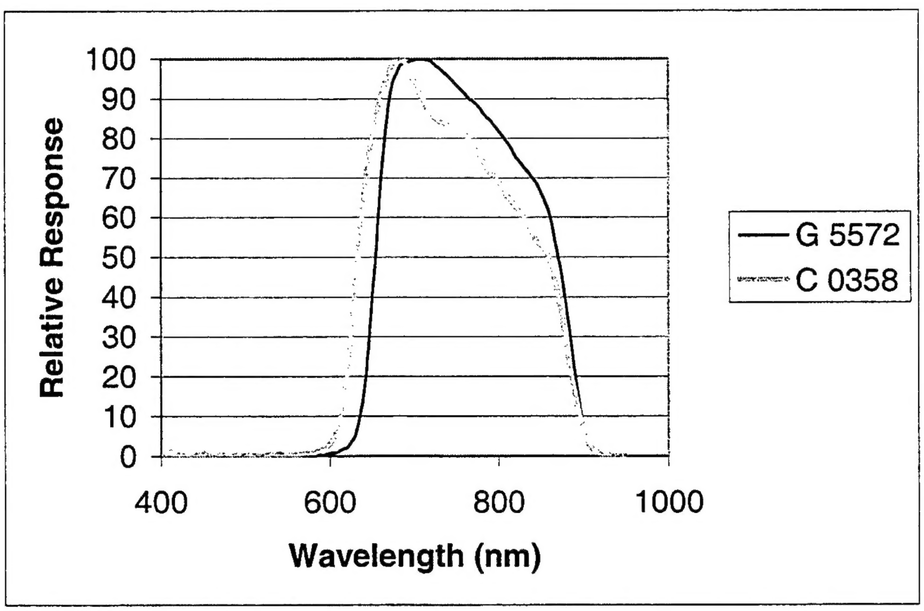

Figure 20. Spectral response, right channels, showing the difference in spectral sensitivity between the two goggles used in the demonstration.

Comparison of the spectral sensitivities of the two goggles yielded an unexpected result. Since the two minus-blue filters were supposed to be similar in nature (Class B and Class C filters), it was expected that the two spectral sensitivity curves should lie nearly on top of each other when plotted together. However, the distinct separation in the curves in the red region indicated that the AN/AVS-9 C model has a Class A minus-blue filter and transmitted more visible light, making it more sensitive to full color cockpit displays.

APPENDIX C

The system gain of the two NVGs used in the demonstration was measured to more thoroughly characterize them. A procedure documented in AL/CF-TR-93-0107 and a Hoffman Engineering ANV-120 gain test set was used to make the measurements that appear in the following plots. The AN/AVS-9, G model goggle was measured to exhibit higher system gain than the C model goggle, as expected.

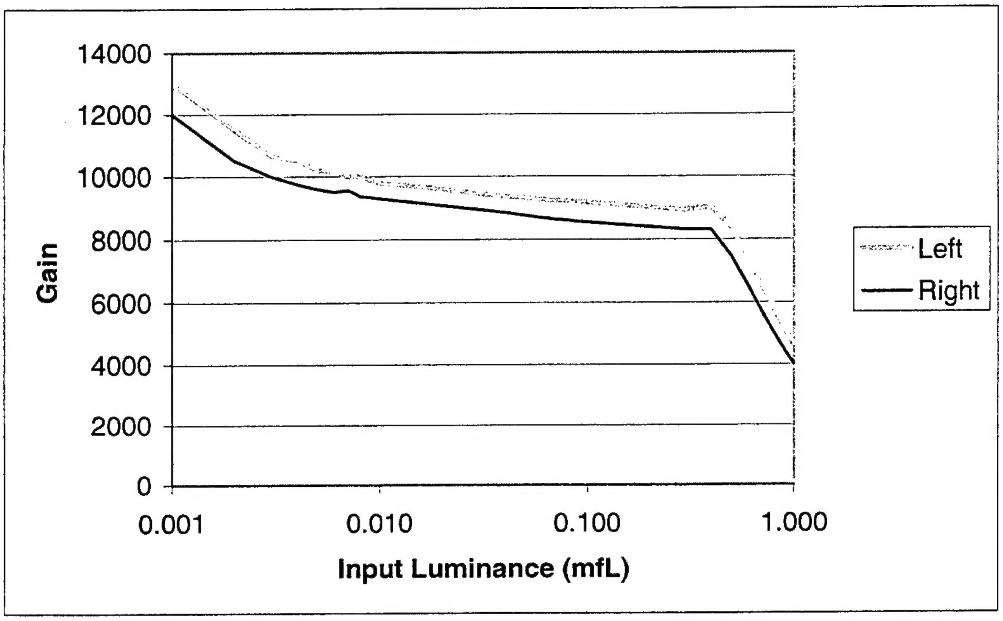

Figure 21. Gain vs. Input luminance for AN/AVS-9, G model, S/N 5572.

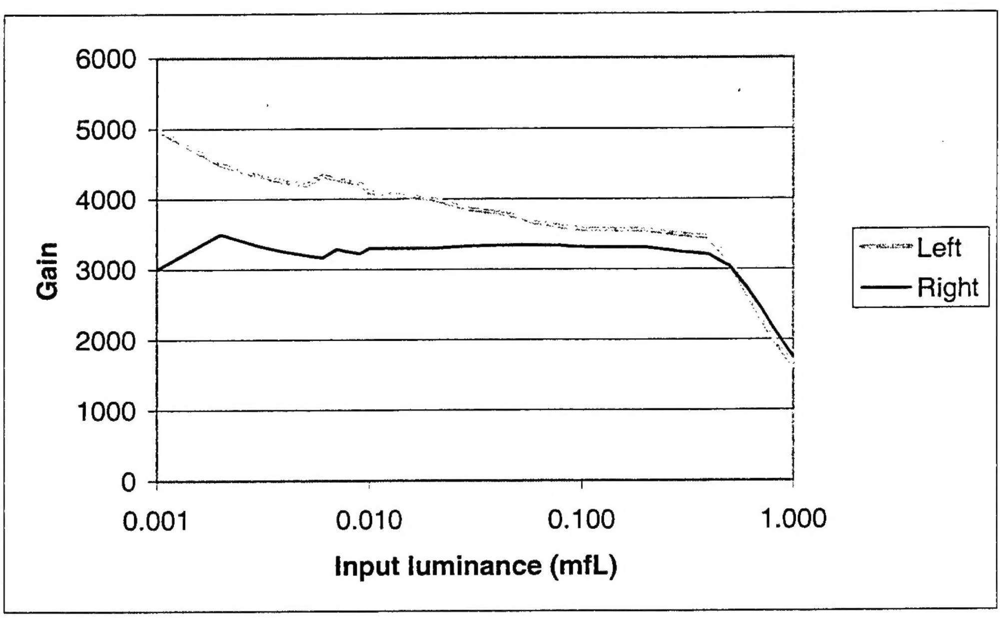

Figure 22. Gain vs. Luminance input for AN/AVS-9, C model, S/N 0358.